NASA SAR Program Elements

Paul A Rosen
Jet Propulsion Laboratory, California Institute of Technology

International SAR Workshop
California Institute of Technology
Pasadena, CA, USA
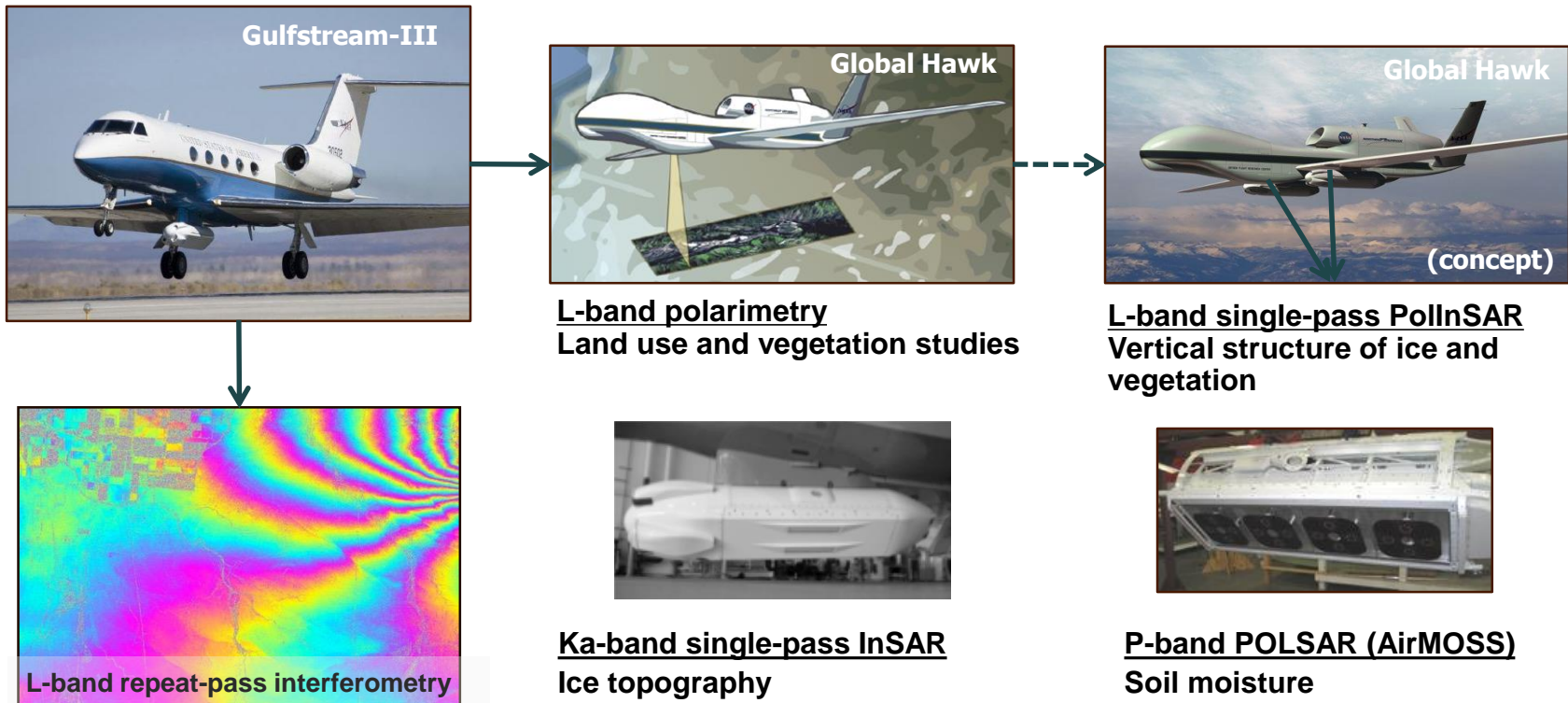May 30, 2018

NASA SAR Program Elements

- Open public access archives to airborne and spaceborne SAR data (Seasat to present)

- UAVSAR Reconfigurable Imaging Radar Testbed for Sub-orbital Science

- NASA-ISRO Synthetic Aperture Radar (NISAR) Mission

- 2017 Decadal Survey Designated Observables associated with SAR/InSAR measurements

- Competed proposals open to NASA centers and academia
  - Science exploiting SAR/InSAR
  - Space radar technologies
  - Software and algorithm development, e.g., ISCE
  - Computational and cloud technologies, e.g. ARIA

Science interests in SAR are global in scope

UAVSAR

NASA/JPL Imaging Radar Science and Technology Testbed

- Conducts science experiments unique to suborbital platforms
- Develops, validates, and improves radar technologies and algorithms for space applications

Gulfstream-III

Global Hawk
L-band polarimetry
Land use and vegetation studies

Global Hawk
(concept)
L-band single-pass PolInSAR
Vertical structure of ice and vegetation

L-band repeat-pass interferometry

Ka-band single-pass InSAR
Ice topography

P-band POLSAR (AirMOSS)
Soil moisture

Mexicali earthquake deformation.
Data acquired on October 21, 2009 and April 13, 2010.
**Major deformation (multiple color wraps) and subtle faulting are visible.**

UAVSAR

L-band, P-band (AirMOSS)

- FY2017 L-band Flight Summary
  54 data flights and 340 flight hours
  - 510 data lines and 12TB raw data
  - Deployments: Colorado, Hawaii, Louisiana Gulf coast, Canada/Alaska, Texas
  - Science: earthquakes, volcanoes, glaciers, levees, snow accumulation, soil moisture, oil slicks, vegetation structure, wetlands, flooding, archaeology, wild fires

- FY2017 P-band Flight Summary
  - 21 data flights and 143 flight hours
  - 209 data lines and 7 TB raw data
  - Science: root zone soil moisture, permafrost active layer thickness, ice sounding

Permafrost from ABoVE campaign

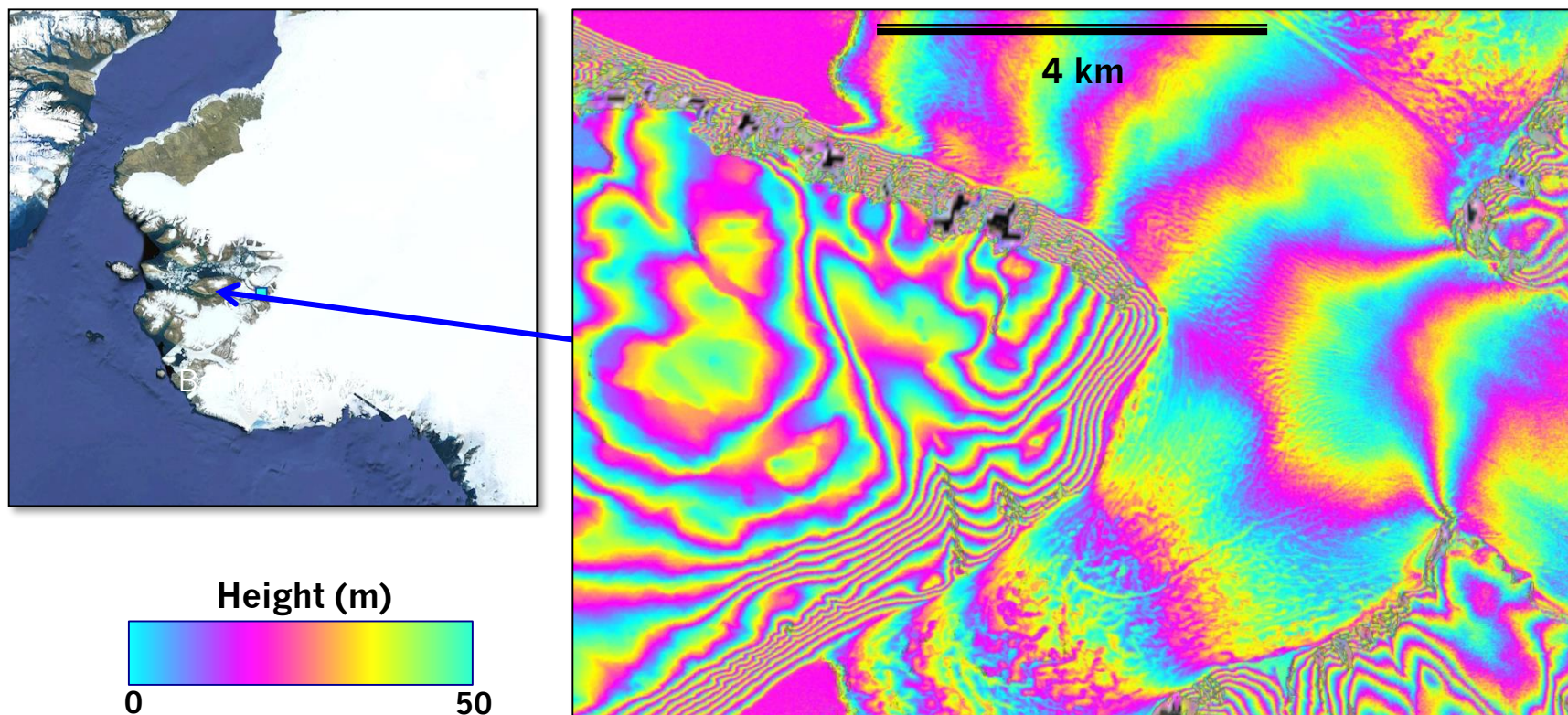LHH LHV LVV   6/21/2017

PHH PHV PVV   6/6/2017
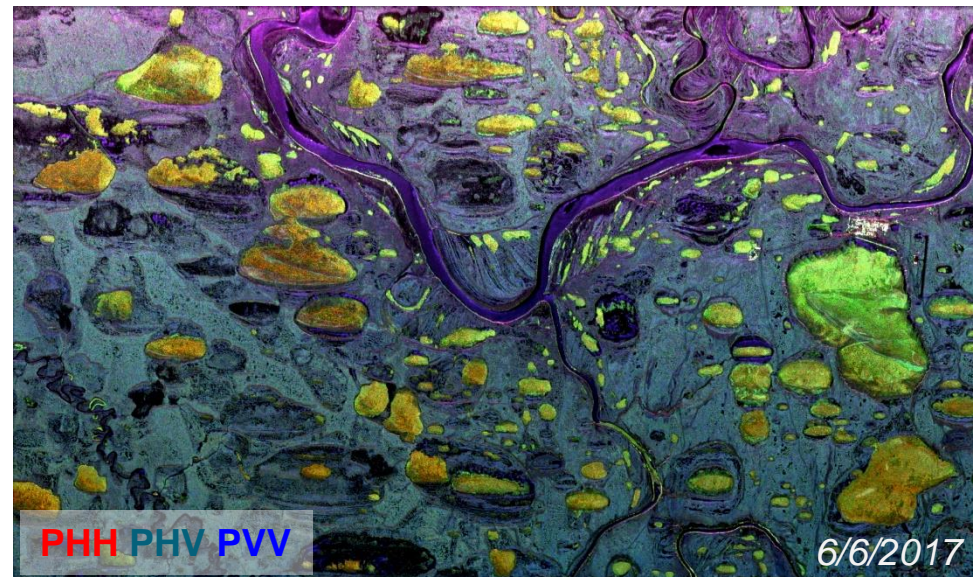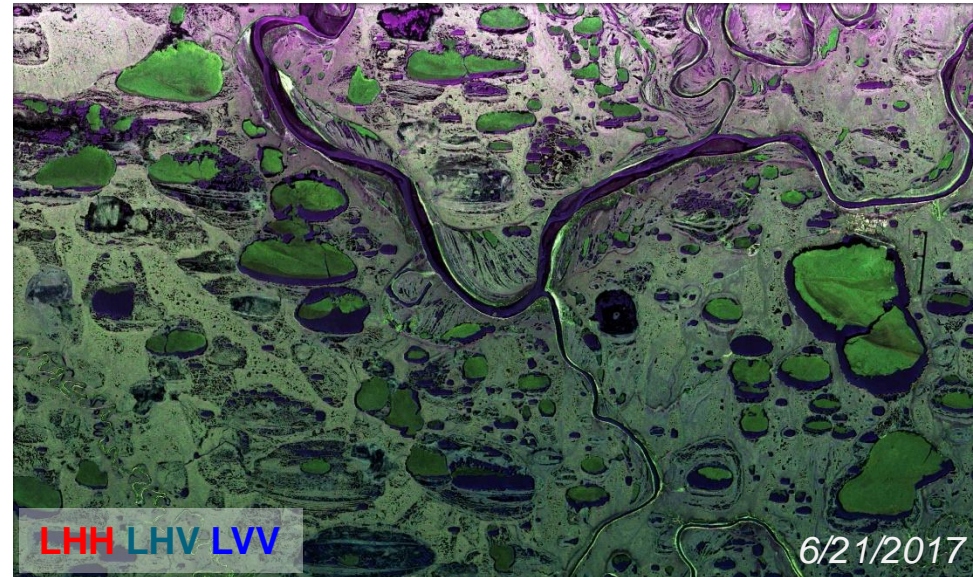
UAVSAR

Ka-band (GLISTIN-A) single-pass interferometry

- Campaigns: Oceans Melting Greenland, SnowEx, Hawaii volcanoes
- 37 data flights (152 flight hours), 305 data lines

March 21, 2017

Leidy Gletscher (top) & Marie Gletscher

UAVSAR

Data collected since 2008

Acquisition (flown)

Successful Data Takes	5,411
Successful Kilometers*	726,875
Successful Raw Data Volume (GB)	137,418
Aborted Data Takes	165
Data Flights	553

*Calculated using length from planned swaths

- Over 180 Publications
- Featured in news regularly
- Deployed for natural disasters when possible
- Free and open data: http://uavsar.jpl.nasa.gov

Successful Data Takes by Discipline

|	
Applied Sciences	839
Biodiversity	3
Cryosphere	465
Engineering	0
Hydrology	386
Land Cover Land Use Change	39
Oceanography	36
Rapid Response	27
Solid Earth (Earthquakes)	1,755
Solid Earth (Other deformations)	532
Solid Earth (Volcanoes)	947
Space Archaeology	12
Terrestrial Ecology	370
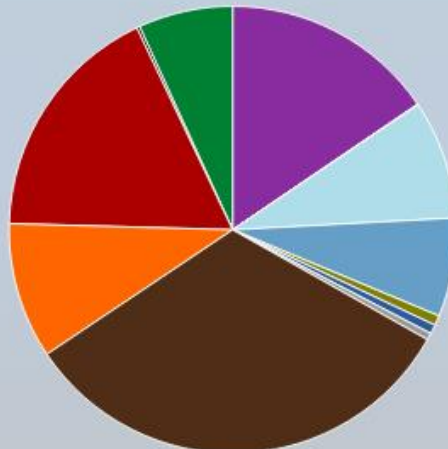
- Applied Sciences (16%)
- Biodiversity (0%)
- Cryosphere (9%)
- Hydrology (7%)
- Land Cover Land Use Change (1%)
- Oceanography (1%)
- Rapid Response (0%)
- Solid Earth (Earthquakes) (32%)
- Solid Earth (Other deformations) (1...
- Solid Earth (Volcanoes) (18%)
- Space Archaeology (0%)
- Terrestrial Ecology (7%)

UAVSAR

Before and After Thomas Fire and Debris Flow Events
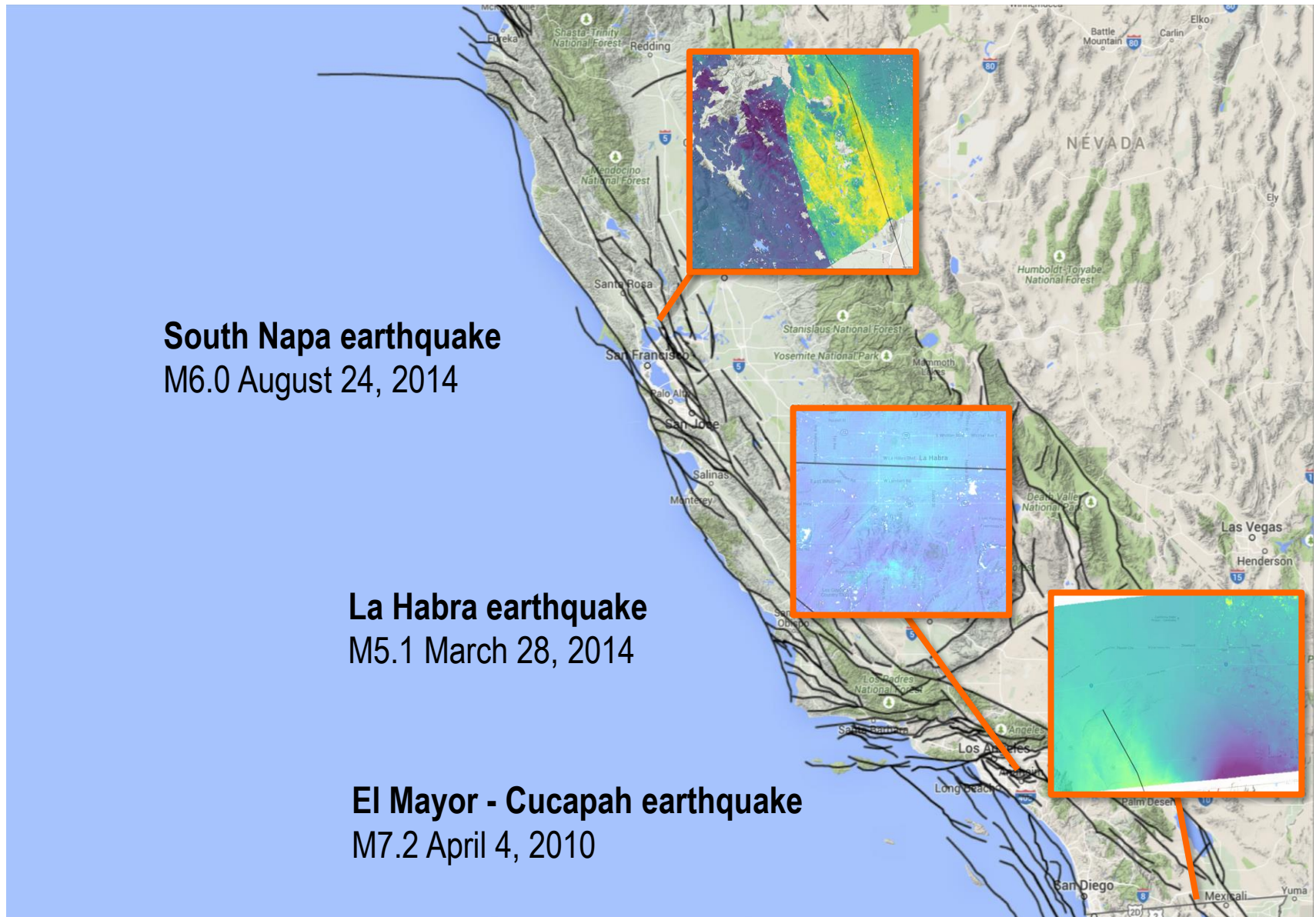
Montecito, CA

Produced February 9, 2018
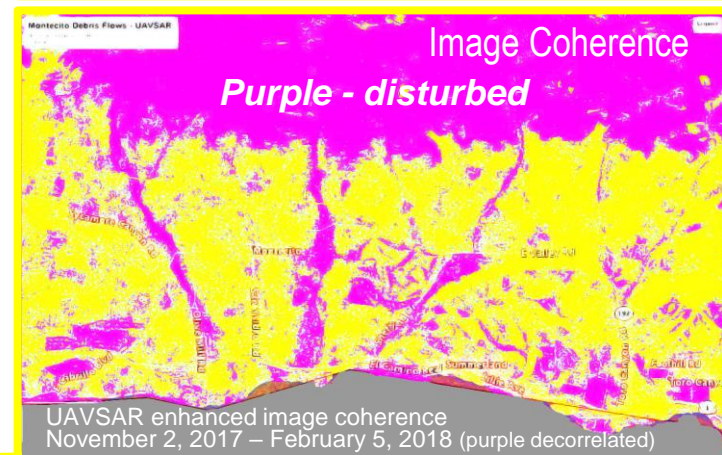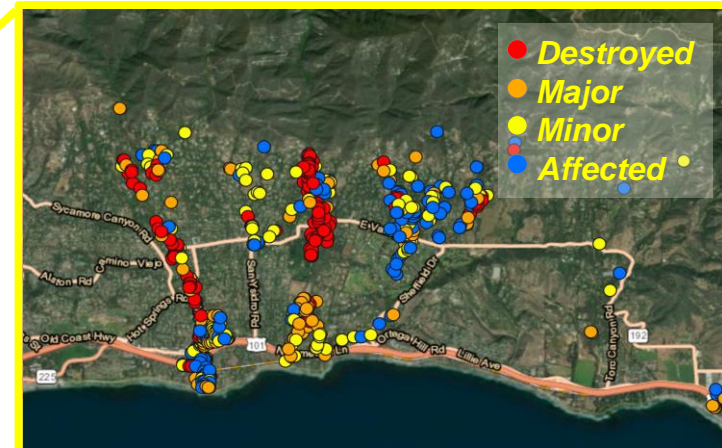
Donnellan, A., J. Parker, C. Milliner, T.G. Farr, M. Glasscoe, Y. Lou, B. Hawkins, in press, Earth and Space Science.

Earthquakes Observed with UAVSAR

South Napa earthquake
M6.0 August 24, 2014

La Habra earthquake
M5.1 March 28, 2014

El Mayor - Cucapah earthquake
M7.2 April 4, 2010

Alaska Satellite Facility

NASA's SAR Archive

- UAVSAR, SeaSAT, SIR-C, AIRMOSS, SMAP, PALSAR-1 Americas, Sentinel-1A/B, ERS, JERS, RADARSAT-1
- Future home of NISAR data archive

NUMBER OF USERS

Web users

Download users

ARCHIVE SIZE

Sentinel-1 Era

Oct 2012

April 2018
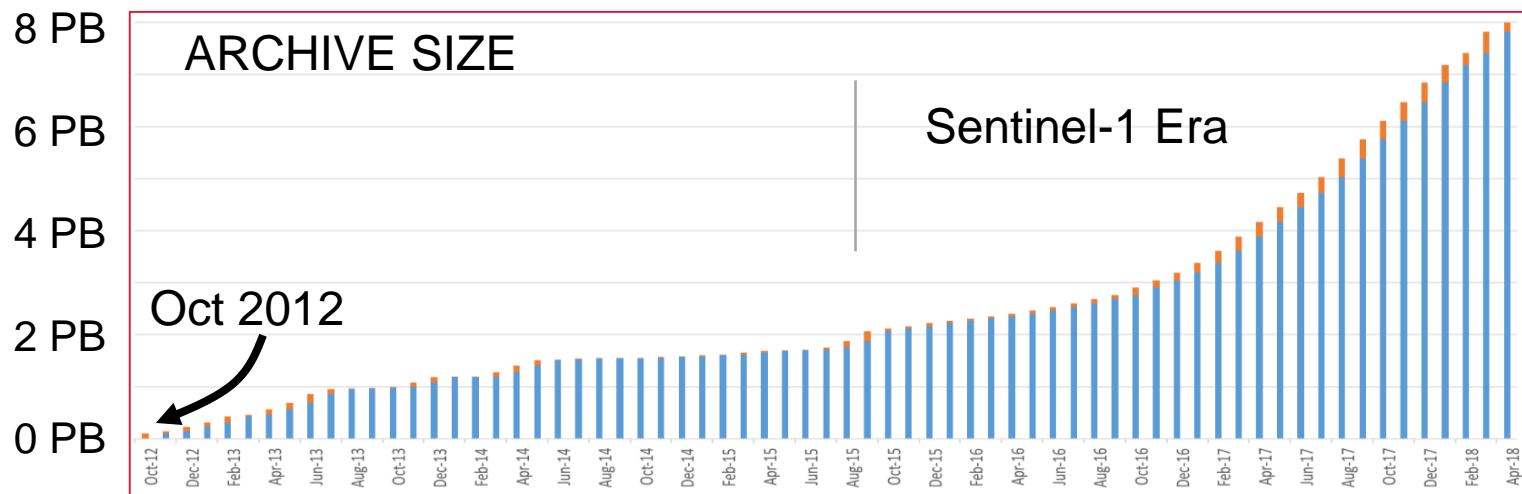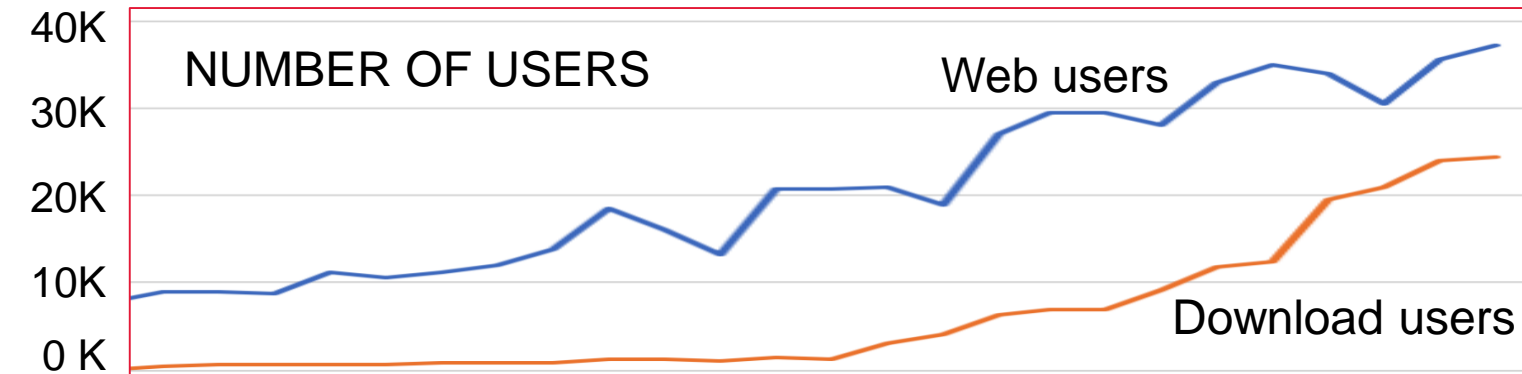
NASA-ISRO SAR (NISAR) Mission

Solid Earth, **Ecosystems**, **Cryosphere** Science and Applications Mission

Jet Propulsion Laboratory
California Institute of Technology

NISAR Characteristic:	Enables:
L-band (24 cm wavelength)	Low temporal decorrelation and foliage penetration
S-band (9 cm wavelength)	Sensitivity to lighter vegetation
SweepSAR technique with Imaging Swath > 240 km	Global data collection
Polarimetry (Single/*Dual*/Quad)	Surface characterization and biomass estimation
12-day exact repeat	Rapid Sampling
3 – 10 meters mode-dependent SAR resolution	Small-scale observations
Pointing control < 273 arcseconds	Deformation interferometry
Orbit control < 500 meters	Deformation interferometry
L/S-band > *50/10*% observation duty cycle	Complete land/ice coverage
Left/Right pointing capability	Polar coverage, north and south
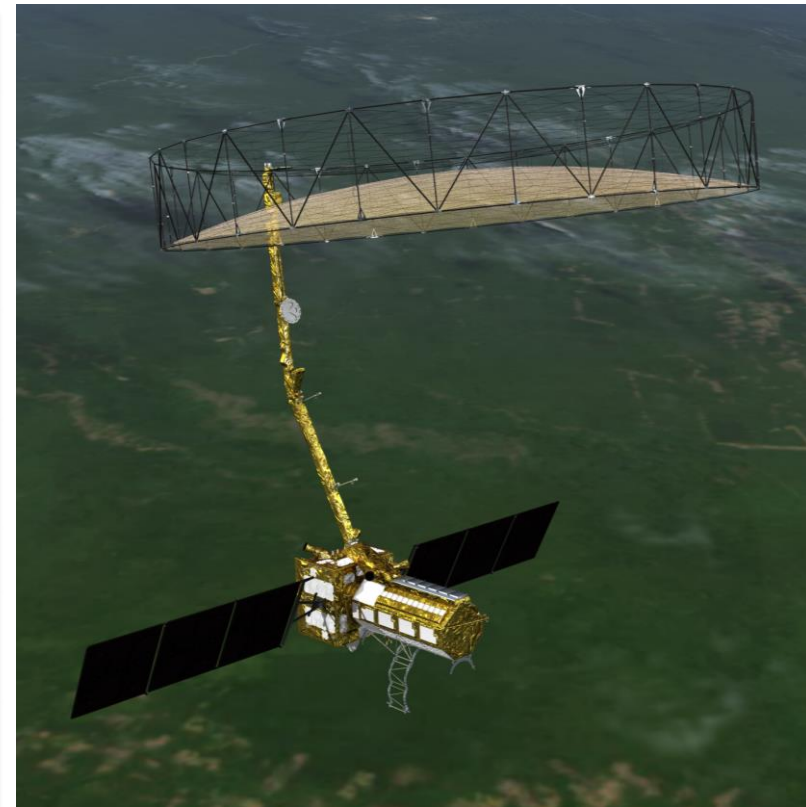
Planned Launch: December 2021

NISAR Science

Capturing the Earth in Motion

NISAR will image Earth's dynamic surface over time, providing information on changes in ice sheets and glaciers, the evolution of natural and managed ecosystems, earthquake and volcano deformation, subsidence from groundwater and oil pumping, and the human impact of these and other phenomena.

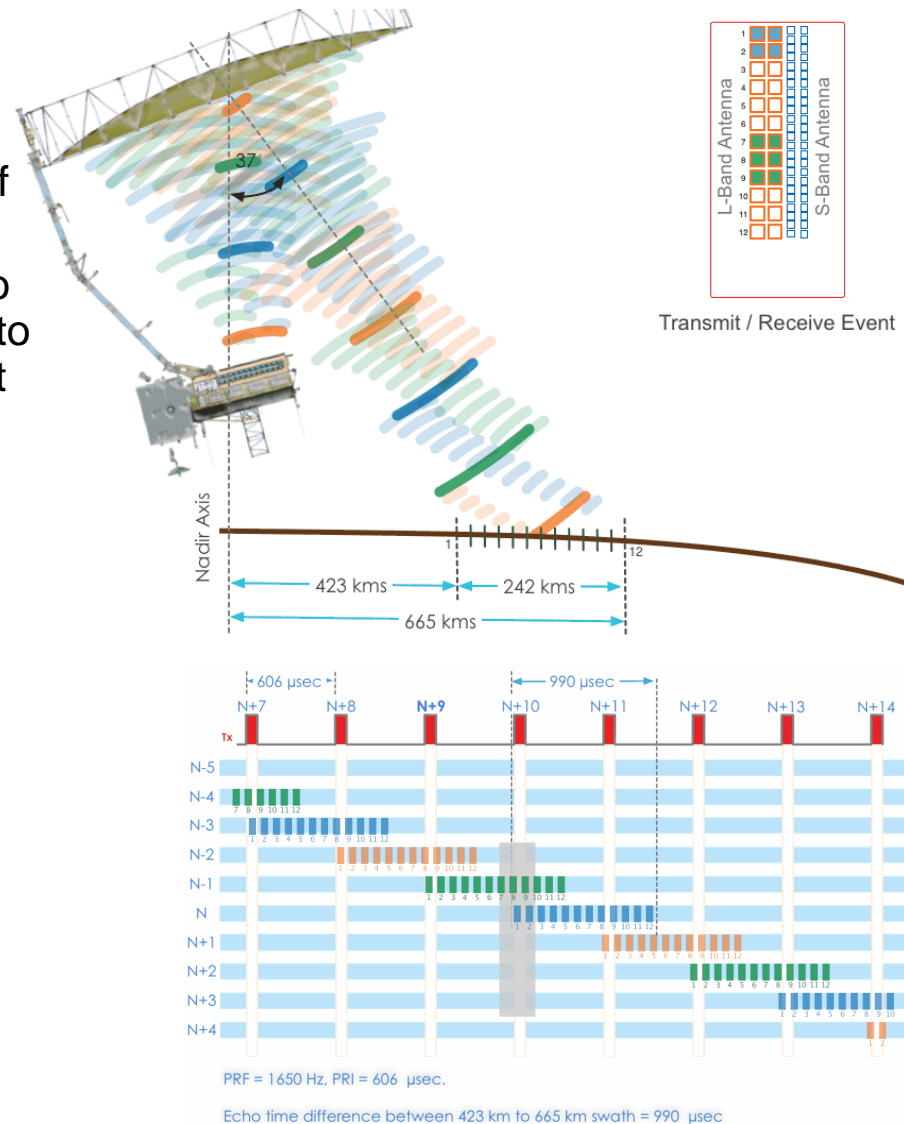# Measurement Technique
Instrument Concept
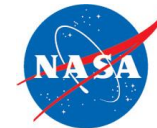
- **SweepSAR**
  - On Transmit, illuminate the entire swath of interest (red beam)
  - On Receive, steer the beam in fast time to follow the angle of the echo coming back to maximize the SNR of the signal and reject range ambiguities
  - Allows echo to span more than 1 Inter-Pulse Period (IPP)
- **Consequences**
  - 4 echoes can be simultaneously returning to the radar from 4 different angles in 4 different groups of antenna beams
  - Each echo needs to be sampled, filtered, beam-formed, further filtered, and compressed
  - On-board processing is not reversible – Requires on-board calibration before data is combined to achieve optimum performance

Transmit / Receive Event

423 kms   242 kms
665 kms

606 µsec   990 µsec

PRF = 1650 Hz, PRI = 606 µsec.

Echo time difference between 423 km to 665 km swath = 990 µsec
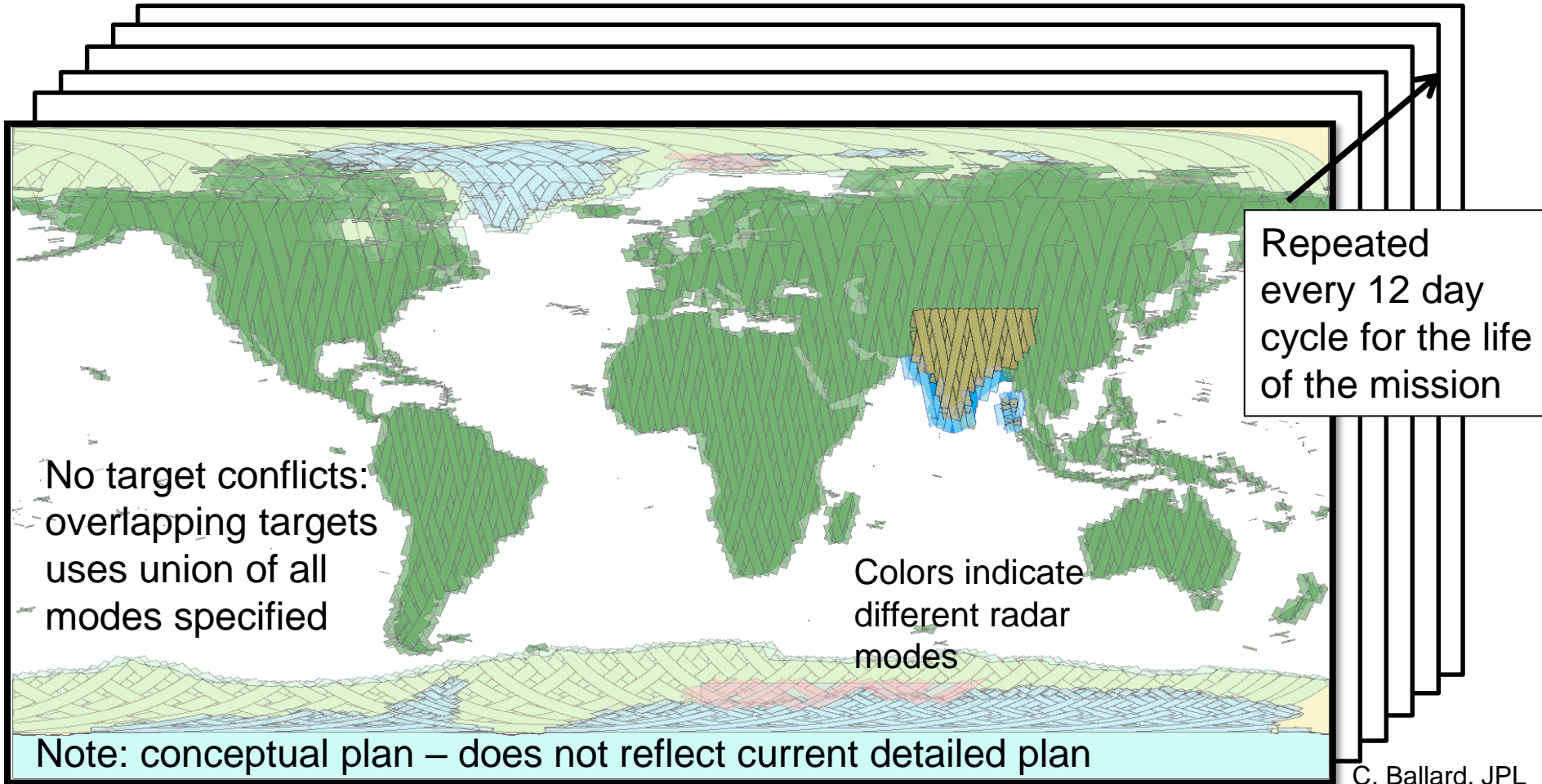
12-day Observation Plan

North (right) looking

- Coverage movie Cycle_07 = January, right

- Greenland mosaic (orange), gaps to be filled in subsequent cycle

- SP observations (odd cycle)(brown)

- Urban areas, streaks of non-coverage from culling 2nd & 3rd days

- 80 MHz SP half-swath mode for Ice Sheets illustrated here as full-swath

Background land L SAR 20+5 MHz DP
Land Ice LSAR 80 MHz SP half swath
Sea Ice LSAR 5 MHz SP
ISRO Sea Ice LSAR 20+5 MHz DP; SSAR 25 MHz CP only descending
Urban areas LSAR 40+5 MHz DP
Agriculture L SAR 40+5 MHz QP
ISRO Agriculture LSAR 40+5 MHz QP; SSAR 25 MHZ QP only descending
Low Data rate study mode single pol LSAR 20+5 MHz SP
Agriculture/Sea Ice SSAR CP RH/RV 25
Systematic coverage LSAR 20+5 MHz DP; SSAR 25 MHz RH/RV CP
High resolution deformation (Disaster/urgent response) LSAR 40+5 MHz DP; SSAR SP HH (or SP VV)75 MH
Systematic Coverage and Deformation L SAR DP 20+5 MHz; SSAR DP 37.5 MHz
Ocean LSAR SP VV 5 MHz; SSAR DP VV/VH 10 MHz

NISAR Systematic Observations

L-band globally – S-band regionally

Repeated every 12 day cycle for the life of the mission

No target conflicts: overlapping targets uses union of all modes specified

Colors indicate different radar modes

Note: conceptual plan – does not reflect current detailed plan

C. Ballard, JPL

Persistent updated measurements of Earth
Global Raw data, Images, Interferometry and Polarimetry Products (50 PB)
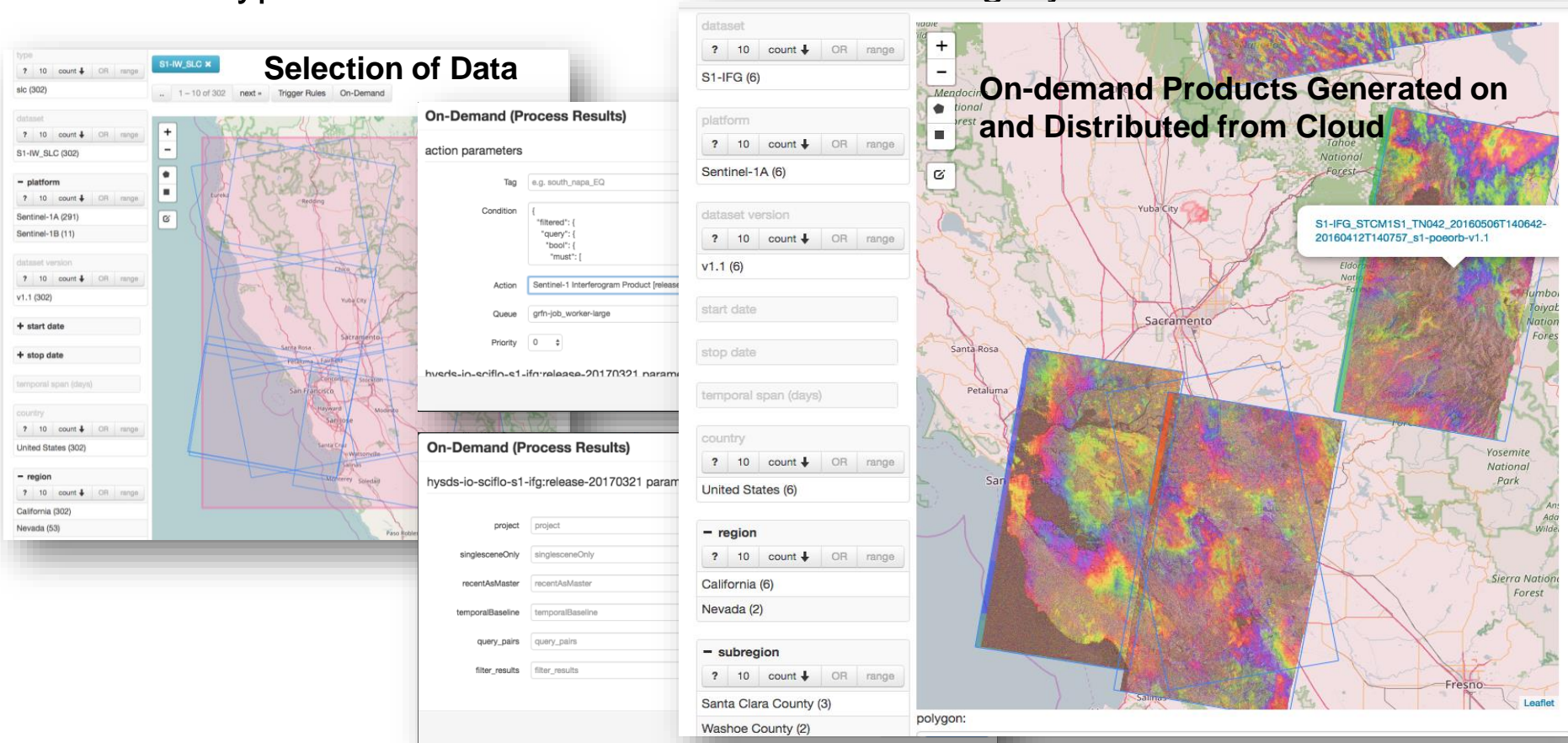
NISAR Global Product Suite

- 26 Tbits of raw data per day on average
- L-SAR L0a, L0b, L1, and L2 science products
- S-SAR L0 science product downlinked through NASA Ka-band
- Free and open archive in Alaska Satellite Facility DAAC
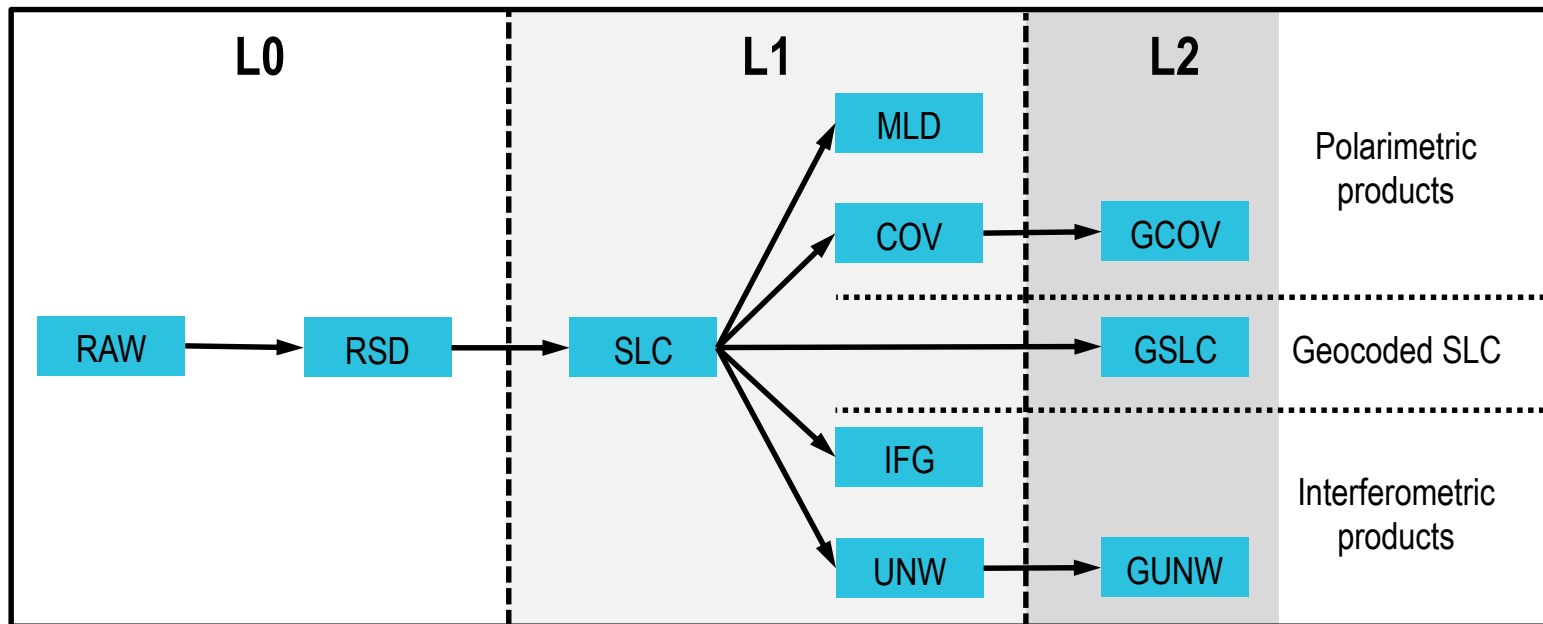
Data Processing and Access Moving to the Cloud

- Cloud Processing and distribution allows scalability and localization with users

- On-demand processing allows users to satisfy their needs without high-capability computing and networks.

- Prototyped with ARIA/GRFN Cloud Processing System

Selection of Data

On-demand Products Generated on and Distributed from Cloud
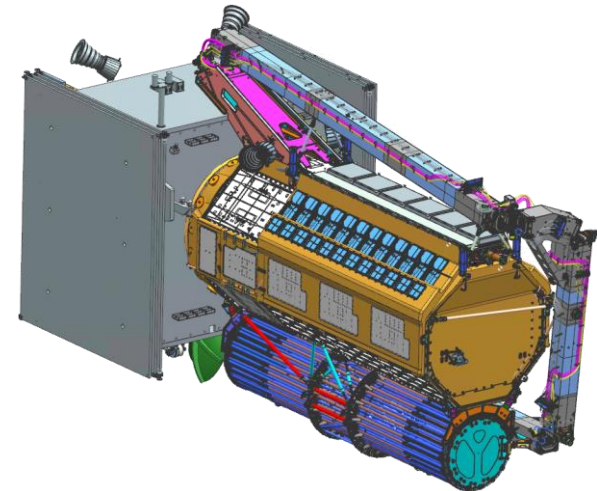
Custom On-demand settings
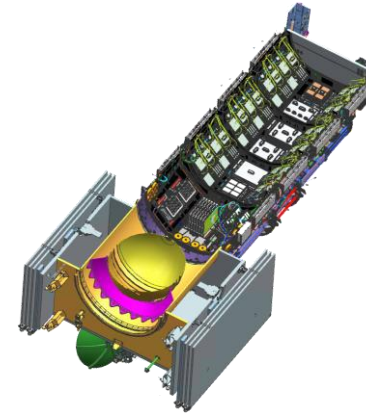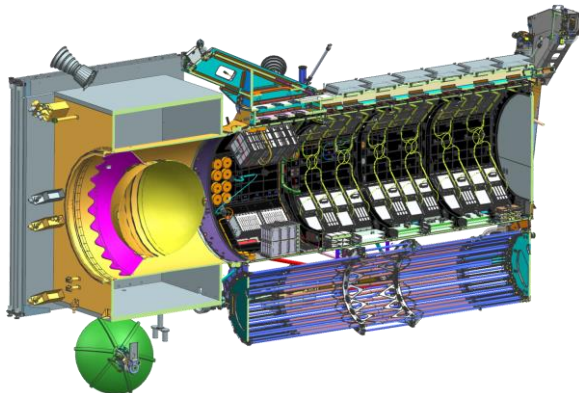
NISAR Observatory

NASA/JPL and ISRO have made significant progress toward building the NISAR observatory
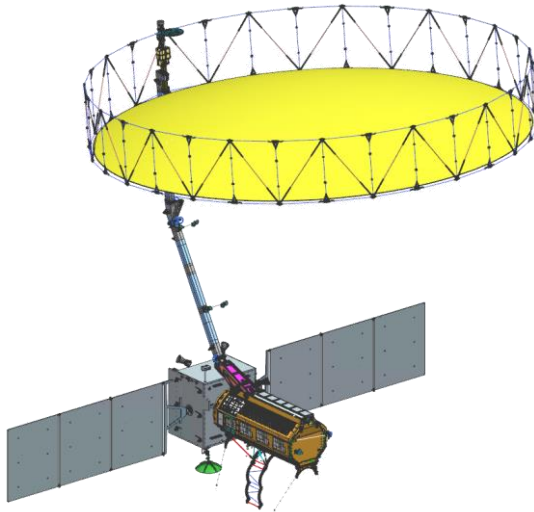
Deployed Configuration

Stowed Configuration

NISAR

Current Status

- Critical Design Review in October 2018
- All Engineering Models, some Flight Models built
- Launch Readiness Date December 2021
- Science Team reaching consensus on a left-only observation plan
  - Would forgo Arctic coverage above 77.5 deg N in favor of continuous time series, greater Antarctic coverage
  - Would rely on Sentinel-1 Program of Record to complete coverage
  - Would be the first (?) example of optimizing the international SAR constellation for science

NASA SAR Program

History of Collaboration

- DLR and ASI:
  - Shuttle Imaging Radar – C instrument
  - SRTM instrument
- CSA: RADARSAT-1 launch and data downlink
- JAXA:
  - JERS cal/val joint activity
  - ALOS PALSAR-1 downlink/ground segment support
- ESA:
  - ERS downlink and archive distribution
  - Sentinel-1 distribution/archive
  - BIOMASS engineering support
- ISRO: NISAR joint mission

NASA supports the scientific exploitation of these and additional datasets through a comprehensive R&A program - including RADARSAT-2, CSK and TerraSAR-X/TanDEM-X

2017 Decadal Survey

SAR Component

- Recommended "designated" observations, addressing five of the highest-priority Earth observation needs
  - Considered foundational elements of the decade's observing plan
- One of the five: Earth surface dynamics from earthquakes and landslides to ice sheets and permafrost
- Suggested spaceborne InSAR as measurement technique
- Recommended < $500M for development to encourage partnerships or lower cost approaches

NASA initiating implementation studies in near future

Summary

- Scientific discovery, exploitation & utilization thrives in an environment of open and ready access to data

- UAVSAR provides unique testbed capabilities for science and technology
  - Development of algorithms
  - Simulation of spaceborne analogues

- NISAR will provide dense spatial and temporal coverage globally
  - Systematic, reliable time series for science and applications

- Post-NISAR mission(s) will likely require partnerships and innovation
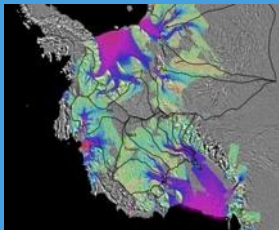
NISAR Mission Overview (Backup)

Mission Science

Distribution of Aboveground Forest Biomass from Fusion of Lidar & Radar
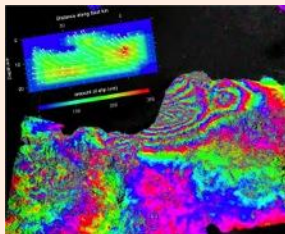
Ecosystem Structure
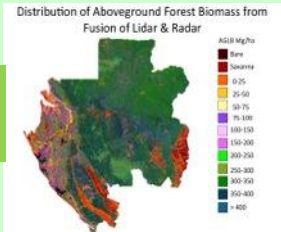
Biomass disturbance; effects of changing climate on habitats and CO_2

Cryosphere

Ice velocity, thickness; response of ice sheets to climate change and sea level rise

Solid Earth

Surface deformation; geo-hazards; water resource management

- Major partnership between US National Aeronautics and Space Administration (NASA) and Indian Space Research Organisation (ISRO)

- Baseline launch date: No earlier than December 2020

- Dual frequency L- and S-band Synthetic Aperture Radar (SAR)
  - L-band SAR from NASA and S-band SAR from ISRO

- NASA 4 Gbps Ka-band telecom system to polar ground stations (> 26 Tbits/day downlink capability)

- ISRO I3K Spacecraft with 2.8 Gbps telecom system

- ISRO Geosynchronous Satellite Launch Vehicle (GSLV) Mark-II (4-m fairing)

- 3 years NASA science operations (5+ years consumables)

- *All science data (L- and S-band) will be made available free and open*